BRIEF STUDY OF LIQUID DESICCANT-BASED AIR CONDITIONING SYSTEMS

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Abstract: *Liquid desiccant-based air conditioning systems offer a promising alternative to traditional vapor compression systems (VCR) by efficiently managing humidity with the help of desiccant material and reducing energy consumption. These systems utilize liquid desiccants, such as lithium chloride, calcium chloride, Potassium format, etc solutions, to absorb moisture from the air, thereby enhancing indoor air quality and comfort. The primary components include an absorber, regenerator, and heat exchangers, which work in a system to dehumidify and cool the air. Recent advancements have focused on improving the efficiency and sustainability of these systems through innovative designs and integration with renewable energy sources. This paper reviews the operational principles, benefits, and challenges of liquid desiccant air conditioning, highlighting its potential for widespread adoption in residential and commercial buildings.*

Keywords Air Conditioning, Contacting Device, Dehumidification, Renewable Energy, Liquid Desiccant

1. INTRODUCTION

With the increasing population density and rising temperatures, the demand for air conditioning has surged significantly. This trend poses a substantial risk of exacerbating global warming, along with the massive consumption of energy and depletion of traditional resources. Air conditioners were suggested for areas where humidity would have a detrimental effect on the comfort level. ACs use a considerable amount of energy but their efficiency reduces with higher moisture removal from the surroundings. Liquid desiccant air conditioning presents a straightforward solution to this issue. These systems can also be powered by non-conventional energy sources, offering a sustainable alternative, pollutant infiltration and comfort. Two types of desiccants widely used as an absorber [5] [8]. These are liquid and solid desiccants, and each of these has its own pros and cons. Modern air conditioning systems have evolved significantly, with liquid desiccant systems emerging as a preferred choice among both researchers and end users. The primary advantage of these systems is their ability to operate with low-temperature heat sources, making them compatible with renewable energy sources such as geothermal and solar power. Specifically, the regeneration temperature for liquid desiccants ranges from 45 to 70°C, which is notably lower than the 70 to 120°C required for solid desiccants. [5]

Another advantage of liquid desiccants is their potential to reduce greenhouse gas emissions. Typically, liquid desiccant systems use direct contact between air and the desiccant solution, often employing packed beds to enhance heat and mass transfer rates. These processes occur simultaneously within the liquid desiccants. However, direct contact can lead to carryover, which negatively impacts indoor air quality and increases corrosion, resulting in higher maintenance costs. To mitigate this issue, the use of membranes has been proposed.

Abbreviations:
LD : Liquid desiccant
LDAC : Liquid desiccant air conditioning
HACS : Heating and Air conditioning system
IHX : Internal heat exchanger
VCS : Vapor compression sytem

2. LITERATURE SURVEY

2.1 Principal of liquid desiccant dehumidification

Figure 1 illustrates the general arrangement for desiccant-based dehumidification systems and common processes associated with these systems. In the dehumidifier, the contacting media allows the air-liquid desiccant contact. The air and the liquid desiccant are brought into contact with each other for heat and mass transfer in both the dehumidifier and the regenerator of the LDAC system. At the juncture, desiccant removes moisture from the air. To continue this cycle, the desiccant must release the absorbed moisture into the ambient environment in a component called the regenerator. Sensible cooling can accompany, precede, or follow the dehumidification process, as the latent heat of water vapor is converted to sensible heat during dehumidification and absorbed by both the air and the liquid desiccant. Additionally, evaporative cooling may be employed after dehumidification to further lower the air temperature. [1]

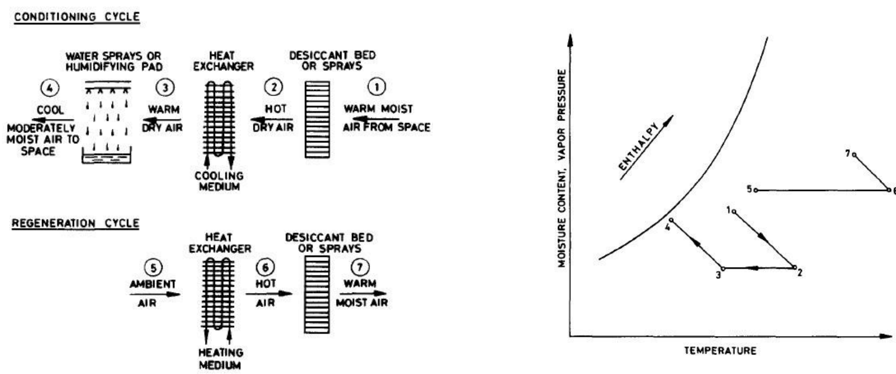


Figure 1. Curves of water vapour pressure at desiccant surface as a function of temperature[1]

2.1.1 Li Huang, Bowen Guan et al [2] have studied the performance investigation of hybrid LDAC system, in hybrid LDAC they have found, heat cold offset to be taken in to consideration as it reduces the performance of system. Conventional system typically adjusts the sensible cooling load up to required demand conditions. And on the other hand, LD dehumidifies the air, but accumulates the sensible load. Hence the cooling provided by the Conventional system and the heat accumulation by the LD system offsets each other. To overcome this, system must be designed as to direct cooling and dehumidification done.

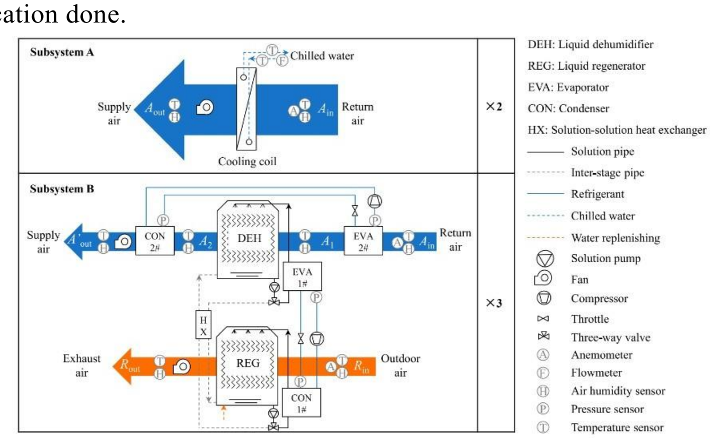


Figure 2. Refined HACS direct cooling and dehumidification [2]

Results: The electrical power consumed by the system is reduced from 166.5 kW to 127.8 kW. Consequently, the COPsys is improved from 2.3 to 3.0 by the refined system under the basic condition [2].

In another study **M. V. Rane and A S Hundiwale [3]**, a novel rotating disk type contacting device is used, in which two circuits are there. 1) Conventional VCR circuit and 2) LD circuit. The VCR circuit cools the LD up to desired temperature, air comes in contact with cooled LD (KCOOH) for moisture removal. Also, it utilises the Condenser heat source for the regeneration of the LD.

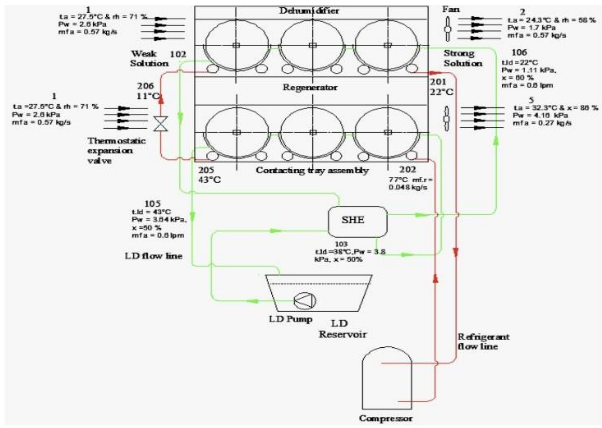


Figure 3. General arrangement of HACS [3]

Results: A 1.5 TR conventional based HACS system was tested, air enters the into the system at 27.5 °C DBT and 71% RH and combinedly cooled and dehumidified to 24.3 °C and 58% RH. Basically, lower values of RSHF are advantageous for hybrid air conditioning system since steeper line enables the evaporator to operate at even higher temperature [3].

2.1.2 Li Zhang et al [4] have conducted the experimental study of the mass transfer in packed bed type liquid desiccant dehumidifier and regenerator using Lithium Chloride desiccant. The setup has the length and width of 500 mm and 270 mm respectively with 250 mm depth of packing. They have found that the mass transfer is significantly affected by the air flow velocity and liquid desiccant flow rate. With increase in velocity from 0.5 to 1.5 m/s, mass transfer coefficient increases from 2 to 10 g/m^2-s and with solution flow rate from 0.4 to 1.1 l/min, mass transfer coefficient varies 5 to 9 g/m^2-s. Increasing the flow rate of either the solution or air will improve the mass transfer coefficient.

The value of mass transfer coefficient for dehumidifier is higher than that of the regenerator. Due to the high temperature of the solution in the regenerator reduces the effectiveness.

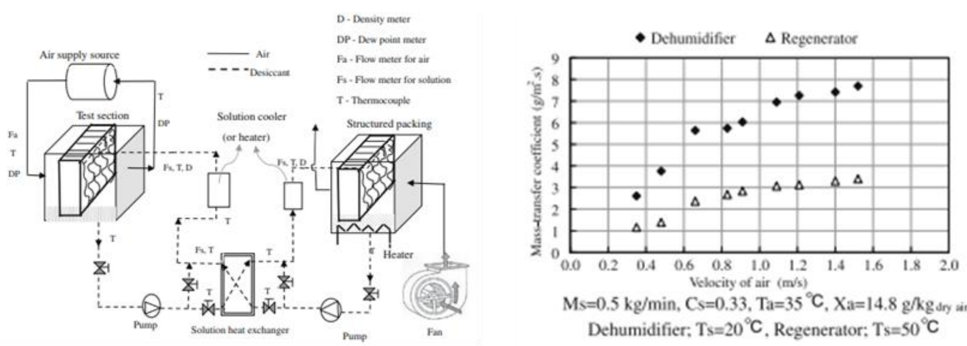


Figure 4. Schematic diagram of the system and Comparison of mass transfer coefficient for dehumidifier and regenerator [4]

V. Oberg and D. Y. Goswami studied [8] the packed bed absorption tower. It was constructed from a 25.4 cm (10 in) diameter acrylic tube to allow for flow visualization. The tower was made in sections so that the bed height could be varied without changing the distance from the liquid distribution to the top of the bed. The inner diameter of the tower was 0.24 m. The packing used was 2.54 cm (1 in) polypropylene Rauschert Hiflow® rings with a specific surface area of 210 m^2/ m^3.

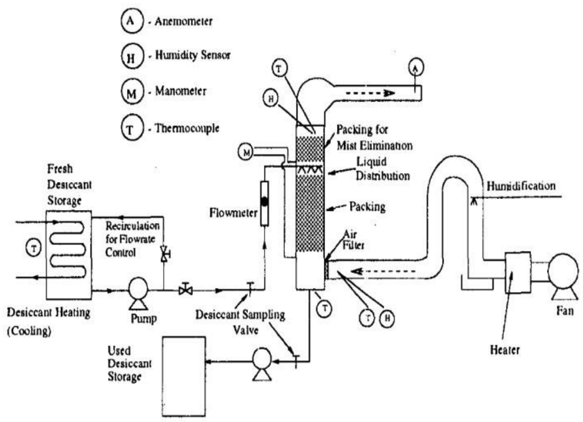
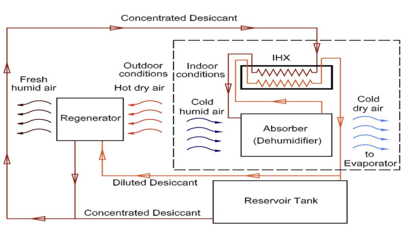


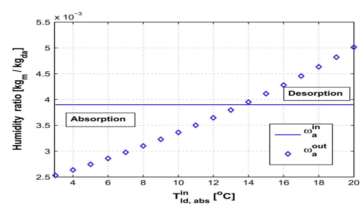
Figure 5. Packed bed type dehumidifier

Results: Performance of the device is greatly influence by the parameters such as Air flow rate and Humidity ratio, desiccant temperature and concentration and packed bed height. The liquid flow rate and the inlet air temperature did not have a significant effect on the dehumidifier performance; however, the liquid flow rate must be high enough to ensure wetting of the packing [8]

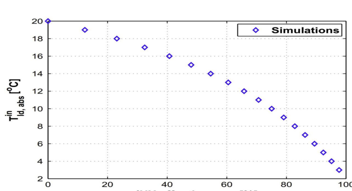
2.1.3 Sergio M. Pineda et al [9] The findings indicate a strong correlation between the performance of the absorber and the effectiveness of the IHX. To achieve air dehumidification, εIHX values need to exceed 60%. Lower IHX effectiveness leads to a higher humidity ratio in the air passing through the mass exchanger. Additionally, the results highlight that the liquid desiccant temperature at the absorber outlet is significantly influenced by the εIHX effectiveness.



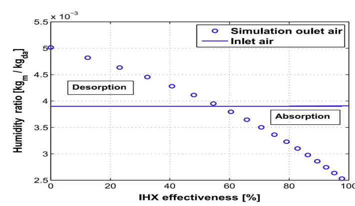
a) Schematics of the system



b) Outlet air humidity ratio vs inlet temperature of the liquid desiccant.



c) T_{ld}^{in}, abs [^{o}C] vs IHX effectiveness [%]



d)Out Humidity ratio vs IHX effectiveness [%]

Figure 6. LDAC with IHX, Sergio M. Pineda et al [9]

IHX is required to be equipped with LD based dehumidification system, while operating under the refrigerated space. If no heat exchanger is used to lower the temperature of LD, then instead of rejecting the moisture, Air absorbed it. [8].

J R Mehta et al [12] has been carried out the performance testing of novel internally cooled LDAD system. Calcium chloride with 41% concentration is used as liquid desiccant with cooling water flow rate of 800 kg/h at 22ºC. They have found that Cooling coil effectiveness can be improved by additional power supply for liquid desiccant flow pump. The system's performance is highly sensitive to inlet air humidity; greater humidity results in better performance. While reducing velocity slightly enhances moisture and enthalpy effectiveness, it significantly decreases the coil's capacity. The system's performance can be further optimized by ensuring a more uniform wetting of the coil.

In another study on internally cooled LDAC, **K. N. Abdalla and A. M. Ahmed [20]** examined the moisture removal rate of a dehumidifier consisting of a packed tower, intake–inlet air ducts, a cooling tower, a strong desiccant storage tank, and circulating pumps. The system utilized a 95% Triethylene Glycol (TEG) solution as the desiccant.

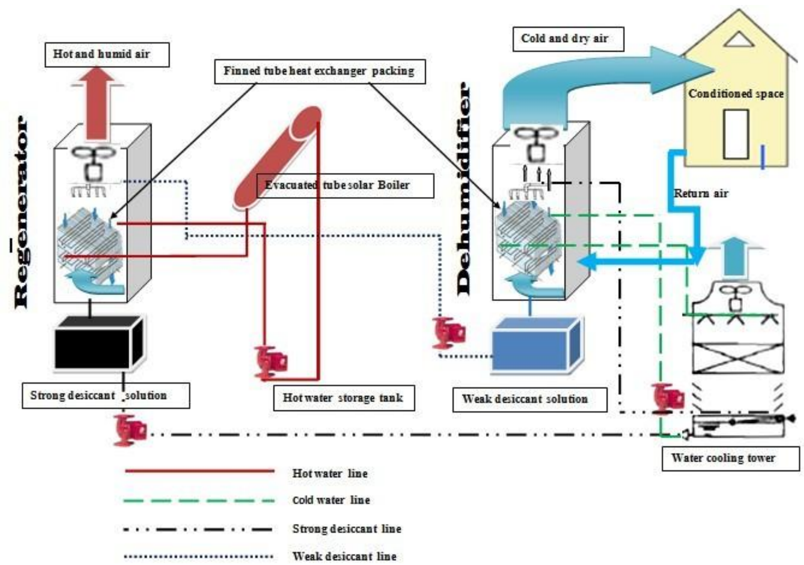


Figure 7. Schematic diagram of the experimental setup [20]

Results: They found that the moisture removal rate increased with either a higher inlet air flow rate or more humid air at the inlet, though this came at the expense of reduction in dehumidifier effectiveness. Alternatively, both dehumidifier effectiveness and the moisture removal rate could be improved by either increasing the desiccant flow rate or using a higher concentration of the liquid desiccant.

2.1.4 Solar based desiccant air condition system also tested for their operation and performance. Such system has advantage as the cooling demand is higher at higher sun insolation. Which leads to effective performance of Solar based liquid desiccant air conditioning system. Solar energy harvesting according to technology may be PV solar cooling, Passive solar cooling, Solar closed loop, Solar open loop, etc. [10]

Basically, three types of Solar desiccant AC system are there.

1. Ventilation mode
2. Recirculation mode
3. Dunkle cycle

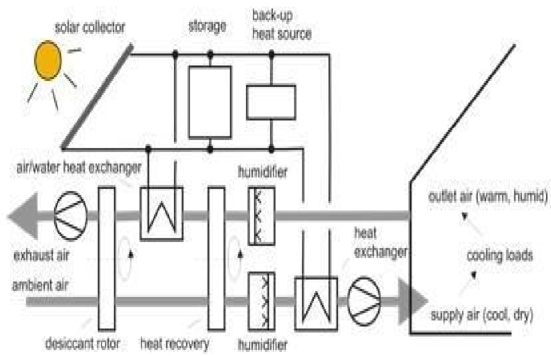


Figure 8. Solar based desiccant air condition system [10]

Study shows Ventilation mode has higher effectiveness and COP as it utilises fresh air for regeneration and cooling purpose as compared to recirculation mode. The COP of SLDAC are generally yields to 1.0. Under low ambient conditions about 25 °C, an auxiliary energy requires for regeneration of LD. Such systems operate on time delay as compared to conventional systems. To reduce air temperature significantly needs 5-10 minutes of and cooling stops after 45 minutes. 0.6 kW energy saving can be achieved for 1 hour run.

Thermodynamic modelling of a hybrid LiBr VCS/Solar collector system showed that 45% energy savings are achieved over standard VCS [6]. The proposed system has minimal hardware requirements, low evaporator operating temperature, small condenser and high dehumidification efficiency. It is recommended for hot/humid climates or for high latent heat loads, since it saves 80% energy at 90% latent heat load [6]. Dehumidification is increased by decreasing the air inlet temperature or by increasing the air enthalpy difference between the dry air and the humid air [10].

Regeneration of desiccants using solar energy can be brought about by different methods. The direct solar regenerators, where the desiccant is itself, the heat collecting fluid, have high effectiveness though they face corrosion, dust and dirt problems [18]. The indirect solar regenerators use solar air or water heater that provides hot water for the desiccant regeneration [18]. The higher water temperature or heat exchanger effectiveness, the greater the rate of evaporation [18]. The multi-stage regenerator uses low temperature heat to treat the weak solution, achieving a high energy utilization ratio [7]. Among the available solar collectors, namely open-type, closed-type, natural convection and forced convection, the forced convection collectors are the most effective and widely used [7].

3. TYPES OF LIQUID DESICCANTS USED

The use of liquid desiccants may be advantageous compared to solid desiccants. According to Howell (1987), the pressure drop through a liquid desiccant system is smaller than the pressure drops through a solid desiccant wheel. Also, the ability to pump the liquid makes it possible to connect several small dehumidifiers to one large regeneration unit (Harriman, 1990), which may be advantageous in large buildings. Finally, concentrated desiccant may be stored for use during the times when no suitable source of regeneration heat is available.

The driving force for mass transfer between the air and the desiccant is the difference in vapor pressure between the air and the desiccant. Hence, the desiccant must have as low a vapor pressure as possible. Liquid desiccants commonly used are aqueous solutions of lithium bromide, lithium chloride, calcium chloride, salt mixtures, and Tri-ethylene glycol

(TEG). As cool and concentrated desiccant is brought in contact with air, water vapor in the air is absorbed by the desiccant, i.e., water condenses into the desiccant. During this process, heat is evolved due to the latent heat of condensation of the water, and the heat of mixing [8].

A liquid desiccant-based dehumidifier relies on the crucial material of liquid desiccants. The capabilities of liquid desiccants for dehumidification and regeneration are determined by properties such as surface vapor pressure, regeneration temperature, specific heat capacity, dynamic viscosity, conductivity, and boiling point. Surface vapor pressure notably influences the efficiency of heat and moisture transfer within the system. [14] Commonly used liquid desiccants include lithium chloride (LiCl), lithium bromide (LiBr), and calcium chloride ($CaCl_2$), with $CaCl_2$ being more economical and LiCl being more stable. [14]

Liu et al. compared the performance of LiCl and LiBr and found that LiCl is a more effective dehumidifier due to its lower vapour pressure, while LiBr has better regeneration performance. However, all aqueous solutions are highly corrosive, posing potential health risks if carry-over occurs during dehumidification. [15]

A new desiccant, potassium formate (HCOOK), is less corrosive and has a lower crystallization temperature, making it a more affordable option. KCOOH performs better than LiCl and LiBr in regeneration tests, it is less corrosive and expensive, fully compatible with the environment and allows significant humidity reductions [3][16][17][18].

Table-1 Comparison between LiBr, LiCl, CaCl2, TEG and KCOOH [3]

Property	**LiBr**	**LiCl**	**CaCl2**	**TEG**	**KCOOH**
Concentration Used	45 to 60%	30 to 45%	35 to 45%	90 to 98%	75%
Regeneration temperature	> 80oC	> 80oC	~55oC	65 to 80oC	~60oC
Toxicity	Low	None	Low	None	Low
Corrosion Hazard	High	High	Moderate	Moderate	Low
Cost /kg	550 INR	650 INR	20 to 25 INR	400 INR	252 INR

The above table highlights that potassium formate (KCOOH) is a viable choice due to its lower toxicity and corrosiveness. It features a lower regeneration temperature compared to LiCl, LiBr, and TEG, though higher than $CaCl_2$. Given its reduced affinity for water vapor compared to common liquid desiccants like LiBr and LiCl, efficient heat and mass transfer equipment becomes essential. [3]

4. CONCLUSIONS

Liquid desiccant air conditioning systems and liquid desiccant materials studied and the summary of the key points derived in this article to reiterate the potential of liquid desiccant-based air conditioning systems to contribute to sustainable and energy-efficient cooling solutions.

1. Liquid desiccant air conditioning systems presents a promising straight forward solution to global warming, depletion of ozone layer and reduces massive consumption of energy, as it can be run by the non-conventional energy sources

as compared to conventional powered air conditioning systems. They offer sustainable alternative, pollutant infiltration and comfort.

2. Hybrid liquid desiccant air conditioning systems can reduce the power consumption. The hybrid system can have higher moisture removal rate for almost the same power consumption. With incorporating the direct cooling and dehumidification of air, the COP of the hybrid system can be improved.

3. The type of packing material selected for the dehumidification purpose is crucial. Structured packing allows for a lower pressure drop compared to random packing, but it comes at a higher cost. Conversely, random packing material has lower performance due to uneven distribution of the liquid desiccant. In the dehumidifier core, airflow resistance decreases with an increase in void ratio, while mass transfer performance improves with an increase in the wetted area. Additionally, the device's performance is significantly influenced by factors such as air flow rate, humidity ratio, desiccant temperature and concentration, and packed bed height.

4. Internally cooled dehumidification units help to reduce the heat discharge and allow lower flow rates, which can improve the performance of the system. Also, the liquid desiccant temperature at the absorber outlet is significantly influenced by the εIHX effectiveness.

5. Lithium chloride (LiCl), lithium bromide (LiBr), and calcium chloride ($CaCl_2$) each have unique benefits: $CaCl_2$ is more economical, LiCl is more stable and has low vapor pressure, and LiBr offers better regeneration performance. However, these aqueous solutions are highly corrosive, posing health risks during dehumidification. Potassium formate (HCOOK) is a promising new desiccant that is less corrosive, has a lower crystallization temperature, and is more cost-effective. It outperforms LiCl and LiBr in regeneration tests, is environmentally friendly, and provides substantial humidity reductions.

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